Digital Reconstruction in Historical Research and its Implications for Virtual Research Environments

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This is an author's accepted manuscript version of a conference paper published in *3D Research Challenges in Cultural Heritage II: How to Manage Data and Knowledge Related to Interpretative Digital 3D Reconstructions of Cultural Heritage* within the Springer Lecture Notes in Computer Science book series (LNCS, volume 10025).

The final publisher's version is available online at: https://doi.org/10.1007/978-3-319-47647-6_3

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Abstract. This articles deals with (digital) reconstruction in historical research and reflects on the use of digital methods within the research cycle. For historians, reconstructions of varying degree, detail and focus are an invaluable research tool. We argue that different stages of reconstruction result in different reconstructed objects, outlining the implications in terms of publication, citation practices and the research cycle. The paper contends that these aspects need to be reflected in virtual research environments. The process of reconstruction needs to become transparent revealing the parameters of the different stages that resulted in the reconstructed product.

Keywords: Digital reconstruction, historical research, virtual research environments, digital humanities, digital methods, publications, research life cycle

1. Introduction

The term *reconstruction* has various meanings and connotations in the humanities. It covers a wide range of processes from the reconstruction of arguments in a historical debate, via the reconstruction of contexts and conditions of research, up to the reconstruction of artifacts. An appropriate reflection on all these aspects goes far beyond the scope of this chapter. Therefore, we will restrict ourselves to the technical and conceptual challenges for the (digital) humanities presented by reconstruction in historical research. Our aim is to highlight the impact on digital research processes which either result in reconstruction or use reconstructions as source. We focus on two aspects: a) the process of digitally recording and publishing reconstructions of physical objects and b) the actual digital reconstruction – two sides of one coin with different implications.

Regardless of specific domains, we classify three levels of reconstruction: the reconstruction of the visual representation of an object, of its historical context, and finally of an object in use. Creators of digital infrastructures, tools and methods need to consider how these levels of reconstruction work together. Each one of these levels bears its challenges—most of them not limited to digital environments.

At all levels, the central challenge is to record the degree of completeness and detail required to justify the historical correctness of the reconstruction. This fosters an environment in which the reconstruction process can be retraced and repeated. This issue is well understood in the natural and life sciences, although it is not completely solved.[1] New standards for data and metadata help in meeting the challenge, as does the integration of technical innovations like new display technologies.

Digital methods will not solve every problem in the reconstruction process and the resulting product but they can make many ambiguities and insecurities more visible, transparent and quantifiable. For example, with regard to publishing reconstructions, digital methods present opportunities for creating a new type of scholarly publication. This qualitative shift towards combined data publication and publications of other research outcomes is discussed in the first section below highlighting the parallels between preservation and reconstruction and their impact on publication practices. We will further identify gaps and issues which need to be addressed by all stakeholders in virtual research environments. In sections 3 and 4, we will debate the different stages of reconstruction resulting in different types of research objects. Section 5 explores the relationship between models and reconstruction. In Section 6, the theoretical assumptions will be transferred to different use cases, highlighting the wide range of applications for historical research. Section 7 identifies the impact of reconstructions on the research process, concluding with consequences for virtual research environments in section 8.

2. Preservation, Reconstruction and Publication

An important aspect of reconstruction is its close relationship to preservation. Heritage institutions such as libraries, archives, and museums, which are dedicated to providing access to cultural heritage material on a long-term basis, have to take this into account. For several decades, digitization campaigns aimed at making library items more accessible while preserving the objects for future use. To preserve at least one copy in case of a disaster hitting the physical object,[2] public and private bodies have financed digitization.[3] When digitization was introduced to libraries on a large

[1] One approach to this is the use of electronic laboratory notebooks; see Rubacha et al. [1].

[2] This is not only an issue in war zones. Other disasters cause irretrievable loss of cultural heritage material, e.g., the collapse of the Historical Archive of the City of Cologne in 2009.

[3] The EC-funded project ENUMERATE is currently running its third survey on digitization practices in cultural heritage in the EU, see http://pro.europeana.eu/enumerate/. The results of the previous two surveys suggest that museums progressed the most in digitizing their collections (24% of analogue heritage collections were digitally reproduced) whereas ar-

scale, questions about the economic and long-term access aspects of digitization strategies arose. Stiller [3] distinguished between three types of digitization in libraries. The first aims to broaden access to the resources, referencing them to make them retrievable online. These digital additions to the physical original object often cannot be considered a reconstruction, as characteristic features might be missing. Examples include digital objects found in aggregation portals such as Europeana,[4] which references digital objects with a thumbnail. The second type is the digital surrogate which is a reconstruction that could be the basis for historical research without consulting the original resource. The scope and level of detail of the reconstruction is often difficult to determine. Of course no object is an exact digital copy of its physical counterpart. The material of an object that bears some historical significance can hardly be reproduced in digital environments yet. The last type of digitization strategy deploys technology to add information to the digitized object, for example through Reflectance Transformation Imaging (RTI), which allows historians to investigate how brushes were used [3].

All these digitization strategies ease decision making for cultural institutions in terms of costs, broader access, awareness and preservation. If the digital representation of an object delivers the same information a scholar could retrieve by consulting the original, this saves the physical object from more damaging handling. The scholar needs to be clear about how the reconstruction was created and which parameters were used. Accuracy in terms of both content and material is a major concern, in case the original object is ever lost.

The publication process is closely related to preservation and reconstruction processes. Every scholarly publication about an artifact asks readers to reconstruct the original objects in their minds. The more information one can add to the replication, the more ambiguities are avoided. This not only strengthens the argument but will lead to a reconstruction that replaces the textual description.

All three processes determine the research cycle, methods, and results, influencing how research objects can be used and re-used. The question is not simply what and how one will publish but also leads to the question of how much the digital reconstruction and preservation impact scholarly publication practices today, and how they can be steered.

3. Stages of Reconstruction

Historians use the term *reconstruction* to mean different things, as illustrated by the following selection of examples. We introduce a classification of terms, which is useful in providing digital tools to support reconstruction processes. We want to emphasize again that we have a very broad understanding of the concept *object*, applicable not only to material objects but also to experimental and investigative procedures.

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chives and libraries (11% and 12 %) lag behind. As the report states, these numbers should be interpreted with caution as the institution size was not weighted in the average [2, p.21].

[4] http://www.europeana.eu/

There are different stages of reconstruction ranging from purely preserving an object in its physical form to the full scientific reconstruction of knowledge acquisition. These stages are often not clearly distinguished, but revealing their characteristics helps to create more transparent virtual environments.

3.1 Reconstructing the Object

The most obvious form of reconstruction is the digital representation of a physical object. Artifacts are scanned or photographed, either to make them digitally accessible as such, or to reconstruct a surrogate for the historical source. The level of reconstruction depends on the research questions and which part of the object carries the informative value. For example, a digital copy of a library book loses none of its information if the text is the research object [4, p.33], whereas a museum object is uniquely defined by its meaning and its interpretation, both of which are almost impossible to digitize. Especially in library digitization campaigns, the objects are considered to be "frozen" as none of their characteristics change over the course of time – the object is complete and whole by itself. Yet a significant amount of information on the materiality of the object is lost. From the historian's perspective, traces of usage and materiality are highly relevant carriers of information about the context of an object.

3.2 Understanding and Reconstructing Contexts of Objects

It is crucial to reconstruct all the information which uniquely identifies the object and makes it valuable for research. While reconstructing the context of an object and the circumstances in which it was created, the problem of clarifying the scope of reconstruction comes to the fore. Archives and museums do more than simply keep documents; they also preserve their provenience and original order. Reconstructing archives in digital environments is an enormous challenge as "the identifiable object of interest in the archive is a complex body of interrelated, unique materials" [5] determined by its context. If this issue is not addressed, researchers are in danger to narrow research on objects only to their digitally reproducible qualities.

3.3 Reconstructing Historical Contexts and (Social) Networks

The mainly material context described above can be broadened to the historical context of an object, that is, the circumstances which surround its creation and use. What are sufficient criteria for completeness of this type of reconstruction process? Thematically arranged digital libraries and virtual research environments belong to this category. Good examples of projects with a long history of context reconstruction include ECHO[5], the Virtual Laboratory (VL)[6] or the ColorConText[7] at the Max Planck Institute for the History of Science (MPIWG).

[5] http://echo.mpiwg-berlin.mpg.de/home
[6] http://vlp.mpiwg-berlin.mpg.de/index_html
[7] https://arb.mpiwg-berlin.mpg.de/

In general, this category includes the reconstruction of living conditions of social groups.[8] Detailing social network reconstruction would go beyond our scope but we are able to provide two examples here: the reconstruction of working conditions in a laboratory and the reconstruction of discovery processes.

3.4 Bridging the Approaches

Digital methods open up a range of unheard-of possibilities. Whole historic sites, their inhabitants and movement paths are brought to life in virtual reality. As the digital reconstruction of context appears so convincing and plausible, it often raises the question of authenticity and historical accuracy, especially in terms of sociological relations. It is difficult for the viewer to judge these parameters, so the risk of historical inauthenticity is real. To avoid accusations of inaccuracy, the process of reconstruction has to be transparent disclosing all the information that leads to the digital representation. In this regard, the development of complex reconstructions is very similar if not equal to a complex research cycle. Combining reconstruction with a theoretical model of the research cycle may make it easier to distinguish hypotheses from reality.

4. The Reconstructed Object

The role of digitization in preserving, archiving, and access to cultural heritage objects has been widely discussed, especially in library and information science [7–9]. Cultural heritage institutions are the driving force in this debate. Their large digitization projects do not only aim to make objects more accessible but also to create a "digital backup". If this endeavor is taken seriously, we need to know how much information about a material object has to be digitally available to reconstruct it if it is irretrievably lost. Obviously, the answer to this question is constantly changing along with the constraints and technical capabilities for replicating, storing, viewing and reconstructing. The "replicator" from Star Trek: Enterprise[9] will never be realizable. It will always only be possible to achieve a partial reconstruction. The amount of information required to reconstruct an object's functionality and form can serve as a guideline. Of course this amount is determined by the research questions. Also, form and function are not necessarily connected. The functionality of an object can be well understood and fully reconstructed without in-depth knowledge of its materiality, and vice versa.[10]

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[8] Analysis of social networks is one increasingly popular method of historical research in this category, e.g., [6]. Maybe the best overview over this topic can be found at http://historicalnetworkresearch.org/. Attached to this is a Zotero group https://www.zotero.org/groups/historical_network_research which compiles most of the relevant literature.

[9] https://en.wikipedia.org/wiki/Replicator_%28Star_Trek%29

[10] One example is the reconstruction of the camera obscura, see [10]. The reconstruction of the creative process of drawing in a manuscript [11]. The University of Oldenburg was at the

In the following, we will describe the different results of reconstruction ranging from the representation of the object in its physical form to the reconstruction of its use and functionality. The aim is to achieve a more systematic view of the problem of reconstruction in relation to preservation, laying the groundwork for answering the question of what and how to store. We see this classification as analytical tool to systematize constraints and demands, and an instrument for the digital humanist to foster a common understanding.

4.1 The Reduced Object

The overwhelming majority of digitization projects reduce the material object to a two dimensional immaterial object by photographic replication. This is true for museums, libraries, and also increasingly now for archives. We do not want to belittle the importance of these endeavors in any way; they are a significant step in the right direction. Projects like Europeana and Archival Portal Europe[11] broaden access to cultural heritage material from various providers.

Significant progress has been made in describing the content of objects. The Text Encoding Initiative[12] (TEI), has created a standard for encoding textual information which is more or less universally accepted for exchanging and archiving textual content. The standards for describing the overall structure of a text with METS/MODS[13] are also highly developed. The same is true of standards for both metadata and for the data itself; archival and presentation formats have been well defined.

The problem of reducing the information value of objects is also discussed in the humanities. For example, Buzetti and Rehbein [12] discuss the problem of representation of text in editions; the fluidity of a text is not fully acknowledged in its materiality. They argue that the problem of static printed text editions, which cannot answer the diverse questions researchers might pose, can be overcome with digital editions. Traces of usage, which in most cases are not directly expressible as additions to the text, are often overlooked in the process of creating digital editions. TEI allows for the description of underlines, manual deletions, and so on, but is limited in terms of describing traces of usage and its impact on the object, for example a fingerprint.

4.2 The Resting Object

Larger technical and conceptual problems have to be solved for resting material objects. Again there are two sides: the metadata and the data itself. This distinction can be blurred. For example, is data resulting from a spectrometric analysis metadata or data describing a given object? Museums are developing standards for describing the

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forefront of reconstructing experiments as part of historical research. See the work of Hans Otto Sibum.

[11] https://www.archivesportaleurope.net

[12] http://www.tei-c.org/index.xml

[13] http://www.loc.gov/standards/mods/

history of an object. For example CIDOC CRM[14] makes it possible to describe the journey of a museum object from the outside world to a museum or archive (be it virtual or real). With this standard, the process of (re)-naming, moving from one place to another, or relevant events in the lifecycle of an object can be described.

Discussing the object itself, however—not only its shape but its materiality—means leaving the safe harbor of standardization. Various imaging processing methods have been developed to represent an object's outer shape and visual structure. Photographic methods ranging from 3D scanning to CT are already used in the humanities.[15] In addition, the materiality of the object is researched and data based on the results of material sciences is collected, for example in art history or archeology.[16] We are still nowhere near a standard for describing and storing all this data to make them available on a long-term basis. We propose an Object Encoding Initiative (OEI) as a logical extension of TEI. In such an initiative, the perspective of potential users has to be incorporated in addition to the provider's view.

4.3 The Object in Action

Finally, we are adding another layer of complexity when we are talking about *objects in action*. Action means reconstructing the production process of the object as well as its use. The object in action adds another dimension to the problem of reconstruction: time.

Although services like Vimeo[17] or YouTube[18] have made it significantly easier to publish movies and animations, how to do this in a scholarly publication remains an open question. The moving images could be linked to background information or parts of the moving object could be annotated so a viewer can understand and trace the production process of the reconstruction in every detail. Reasonable progress has been made in publishing annotated films online, such as projects in Heidelberg[19] and Nijwegen,[20] but this is still a niche.

Adding sensory information about touch, smell or taste to the reconstruction is an almost impossible endeavor. A recent workshop at the MPIWG[21] discussed the reconstruction of paint making on the basis of historical artists' recipe books and the analysis of paintings. This is a striking example of interdisciplinary collaboration between art historians, general historians, conservators, chemists and physicists, all working together to reconstruct a historical process. It also shows the complexity of document-

[14] http://www.cidoc-crm.org/

[15] E.g., for statues http://www.iflscience.com/technology/ct-scans-reveal-mummy-inside-statue, and the "Ancient Lives" exhibition at the British Museum http://www.britishmuseum.org/whats_on/past_exhibitions/2014/ancient_lives.aspx

[16] Material data and scholarly analysis also need to be combined in other contexts, e.g., ink analysis to date the writing on a manuscript, e.g. [11].

[17] https://vimeo.com/

[18] https://www.youtube.com/

[19] http://kjc-sv006.kjc.uni-heidelberg.de:8083/home

[20] https://tla.mpi.nl/tools/tla-tools/elan/

[21] https://drupal.mpiwg-berlin.mpg.de/workshops/node/63

ing the process of reconstruction and its outcomes. For example, sensory impressions like judging the consistency by touching or the success of a reaction by the smell, which are documented in the historical recipe, need to be part of the reconstruction process.[22] This requires convergence of the digital documentation techniques used by the different disciplines, including the scientist's electronic laboratory book and the detailed visual representation of the outcome supported by visual artists.[23]

4.4 Challenges of Reconstruction

The major Problem of reconstruction is the level of completeness and detail. These questions arise when thinking about the reconstruction of objects: How much detail is needed to answer the research question? How does one ensure that the reconstruction corresponds to the historical object? Where can detail be lost without influencing the results? Another challenge is that the digital reproduction might be perfect, but the end user device might not be suitable for display (e.g. the screen might be too small or incorrectly calibrated). This becomes even more crucial when the reconstruction is used as the primary source. What level of accuracy is required to ensure good scholarly practice? Dalbello [13, p.494] elaborates this point in the realm of digital editions:

"Because texts are generated and constructed over time and tradition, they are constantly developed and mutated, and an archive supporting textual studies should represent that historical cumulative generation – involving authors, editors, typographers, book designers, and publishing agents, all those who are constructing the materiality of literary text. Therefore, a meaningful scholarly archive stages documents to preserve the context of their creation and materiality accompanying literary creation."

The problem of completeness concerns all levels of reconstruction and all research objects in all disciplines. Where can one draw the line? How does one determine how well the reconstruction is presenting the object, its context and its network? One solution is to reveal and show the workflows and parameters which resulted in the reconstruction.

5. Models and Reconstruction[24]

Reconstruction as an historical method is closely linked to the concept of a *model*. Although the term has been used in various contexts in science and the history of science, it is impossible to find a concise definition. Models are involved in all historical periods and stages of scientific work, from problem setting to teaching and popularization. Their meaning varies from models as abstraction and simplification to

[22] For online representations of color recipes, see the "Colour Context" database: http://web.philo.ulg.ac.be/transitions/colour-context-2/ and the database of medieval and early modern art technology recipes by Doris Oltrogge: http://db.re.fh-koeln.de/ICSFH/forschung/rezepte.aspx

[23] This insight is not new. The collaboration of artists and scholars in print has been a topic of historical research for decades.

[24] The longer version of this section can be found in [14].

models as copies that are intended to be as close as possible to the original. Models can be material objects, theoretical concepts or cognitive structures for knowledge organization. De Chadarevian and Hopwood [15] investigated the potential of working and researching the use of 3D models for the history of science. In their introduction, they outline the establishment of a research program focusing on scientific practice and the ways in which scientific knowledge is conceptualized and communicated. The research program resulted in two-dimensional (2D) representations becoming a subject in the history and philosophy of science, constituting a "science around visual languages and working objects" (p. 2). Three-dimensional models remained neglected. As Ludmilla Jordanova [16] points out in her commentary, this was encouraged by academic practice in the humanities, where textual representation was the primary language of scholarly communication. Two-dimensional models in the form of graphical representation were only used as illustrations of otherwise textually communicated analysis. This traditional division narrowed the scope of research, neglecting both non-textual representations and practical knowledge. Griesemer defines 1D and 2D models models as "1D linguistic or symbolic expressions" as part of logical empiricism, and "2D, non-linguistic, pictorial, diagrammatic, and graphical displays" [17, p.433]. Three-dimensional models have very diverse uses, including mathematics, anatomy and molecular biology, all of which directly aid the understanding of abstract concepts and otherwise physically inaccessible objects. Material models can be used for learning by assembling and reassembling constituent elements, which is often not possible with the real object. The whole body and all the senses are involved in learning through exploration. Thus the principles required to understand how the model functions are more easily accessible than the principles governing the complex real object. The model allows the principle of knowing-by-making to be extended to the end user.

6. Use Cases and Examples of Reconstructions in Historical Sciences

To demonstrate the variety of reconstructions in research into the history of science, this section presents some use cases in digital environments and their effects on research questions and methods. These examples from our own field cannot represent all possible use cases but they illustrate the challenges faced in reconstruction. Thus they complement the more detailed strategies explored elsewhere in this volume.

The presented projects take different approaches to historical reconstruction. They aim to aggregate material and create a knowledge base which can be used for discovering new connections within the digitized material, fostering scholarly exchange through collaboration and using technology to answer specific research questions. Renn understands these connections as harbingers of the "Epistemic Web: a Web optimized for the representation of human knowledge and its global processing" [18, p.10].

The Virtual Laboratory (VL of physiology)[25] is a platform initiated by a project hosted at MPIWG and initially supported by the Volkswagen Foundation. The platform aggregates resources on "the experimentalization of life".[26] The digitized resources are available in various formats, cross-referenced and augmented by a collaborative space where researchers can share their collections publicly. The navigational structure of the materials and the possibility to pivot browse through the collection was envisioned to generate new research questions and insights [19]. From the beginning, this project was designed to be more than a comprehensive digital library (although when it started in 1996, this was already an ambitious project). It was intended to be a virtual environment which recreates and reconstructs researchers' access to sources and materials in a 19th century laboratory, augmented by their connections to colleagues and affiliations. The aim was to understand the conditions under which decisions were made in the lab. The reconstruction process itself is done by essays published in the lab and linked to the material in the VL. Its design and continuous adaption was driven by the interests of the researchers involved in the project.

As early as 1998, Peter Damerow and Robert Englund envisaged that a digital library was needed for research into the origins of writings and calculations.[27] This could bring together the fragmented collections of cuneiform writing on clay tablets held by museums spread around the world. They wanted to gather collections of high quality images and transcriptions of the calculations written on the tablets in computer readable forms. The goal was not only to collect and combine existing sources but to create an infrastructure for reconstructing the empirical contexts in which writing and calculation could have emerged. Similarly, the Archimedes project[28] created a digital research library for the history of early modern mechanics.

In their groundbreaking work, Paolo Galluzzi and his team at the Museo Galileo physically and virtually reconstructed the instruments and experiments used at the time of Galileo Galilei and Leonardo Da Vinci.[29] Their work shows how detailed historical research and reconstruction methods lead to a deep understanding of the knowledge structures behind early modern mechanics, combining scholarly and practical knowledge. It demonstrates the power of the virtual exhibition as a tool for communicating scholarly research results by setting reconstruction in a wider context. This strategy was also taken up in creating the virtual exhibition[30] about Albert Einstein's discoveries and their context which complemented the physical exhibition at the Kronprinzenpalais (Crown Prince's Palace, Berlin) [23]. The infrastructure is

[25] http://vlp.mpiwg-berlin.mpg.de/

[26] http://vlp.mpiwg-berlin.mpg.de/about/goals.html

[27] http://cdli.ucla.edu/, for the context of counting and calculation methods in reconstruction, see [20], and for a brief history of computer aided reconstruction seehttp://damerow.mpiwg.de/doku.php/obituary. The history of this early digital humanities project still has to be written.

[28] http://archimedes2.mpiwg-berlin.mpg.de/archimedes_templates

[29] see [21] and the website of the museum http://www.museogalileo.it/en/index.html, for the wider context, please refer to [22].

[30] http://einstein-virtuell.mpiwg-berlin.mpg.de/VEA/SC879771616_en.html

designed to be continuously extended by researchers, also after the end of the physical exhibition, to show new insights into the history of modern physics.[31]

All these projects aim to provide a historical research basis contextualizing the different objects with cross-links and digital references. This approach provides scholars with the opportunity to review, search, and work on a corpus of objects that represent a certain research field. It allows them to quickly get an overview and use the material online from their desk. The level of reconstruction in these digital libraries is diverse. The decision whether the digital object is sufficient depends on the research question.

A completely different approach to reconstruction was taken by Gerd Graßhoff und Michael May in 2003 in their work on the urea cycle [24]. They developed an epistemic model that could be implemented as a computer program. So they were able to computationally reconstruct the process that took place in the laboratory of Hans Krebs and Kurt Henseleit. The outcome of this reconstruction was a full simulation of the scientific discovery process.

The extensive field of computer-aided archeology can only briefly be mentioned. Digital reconstruction often supports scientific discovery when the original research object is no longer complete. This is particularly important for archeologists, who rely on reconstructions and models to support scientific discovery [25]. Graßhoff and Berndt [26] reconstructed the design principles which guided the portico columns of the Pantheon in Rome. To achieve this, they not only accurately measured the properties of the site, but also reconstructed the knowledge base that was needed to come up with the given design principles at the time. Saldaña [27] presents a framework for creating 3D models used in archeological research that lets the researcher determine rules for selecting information and contexts for the modeling process and its iteration. The goal of this procedural modeling approach is a 3D model whose creation can be reproduced by tracing the underlying sources and information.

The above examples show that there are promising and successful developments in historical research. These cases exploit technologies to reconstruct historical information which can be used to make relations between historical objects more evident. They also show the ongoing challenges to date: projects are still isolated and only loosely connected to outside contexts. To change this, reconstruction could be embedded more directly into the environments which scholars are using, enabling seamless integration. The next section explores how reconstructions fit into the research life cycle and can be products of such a cycle.

7. Reconstruction and the Research Life Cycle

Research life cycles can be designed to clarify the humanist's research process and to enable infrastructure stakeholders to better adapt their services to the needs of scholarship. They act as blueprints to better support the processes of creating reconstructions.

[31] http://virtualspaces.sourceforge.net/

Cluster 1, the work package for accompanying research within DARIAH-DE,[32] developed a model of the research life cycle looking at the research activities, their immediate output and their results as a form of knowledge generation [28]. This life cycle was based on the activities and primitives developed by Unsworth [29], Hennicke et al. [30] and TaDiRAH.[33] Each activity within the research cycle produces output in form of data that is the basis for the next activity. For example, exploration and discovery will yield an aggregation of sources, articles and data. This output will be used in the next activity—sampling and aggregating the research corpus. Some of the output of each research step will generate new knowledge that should be preserved and referenced. The corpus of sources might mark the beginning of the research process, and the publication often marks the end. Both these products of knowledge could be shared with other researchers and the public.

It is clear that such a life cycle can only be a simplification of the actual research process in the humanities. Often activities do not follow one another like pearls on a string; instead a mixture of processes can run simultaneously. Nevertheless, it is essential to understand the research activities and their products to better support and reproduce them in a digital environment. Seamless integration of all activities and their products in the research cycle without gaps in data processing and management is the goal of digital research infrastructures. These cycles are not static models but frameworks that focus on the needs of scholars. They can help to identify tools and services for the various tasks of their work.

Theoretical cycles can serve as indicators for reconstructing knowledge processes in digital environments. Knowledge production is enabled not only by the different levels of reconstruction of the research objects but also by reconstructing the foundations of research. Making reconstructions re-usable for other scholars necessitates coherent reconstruction of the research process that generated the results. The prerequisite is that all results should be useable in other contexts so that they can be revised and improved. To achieve this, each knowledge product generated in the research process and its interpretation needs to be preserved and referenced. The reconstruction of digital research practices has wide-ranging consequences for the publication process in the humanities and for the development of virtual research environments.

8. Consequences of Reconstruction for Virtual Research Environments

Virtual research environments that aim to support the full research cycle need functionalities which adhere to the standards and expectations of their users. One has to distinguish between the needs and requirements researchers have regarding (1) the use of digital tools and services and (2) research practices in the different disciplines. Within DARIAH-DE, Stiller et al. [31] aggregated requirements and needs from researchers in the arts and humanities. General requirements applying to digital tools

[32] https://de.dariah.eu/

[33] https://github.com/Tadirah/TaDiRAH

and services include thorough documentation and technical stability [32]. Important requirements for the humanities include research specific requests for long term accessibility of the research data [33]. Requirements concerning the practices of historical research are rare. Boonstra et al. [34] point out that historical information science needs to solve four problems which are directly related to the development of virtual research environments. Historical sources need to be connected to interpretations, they are defined by relationships with other resources, historians need tools that can take changes of time and space into account, and there is a lack of presentation techniques and tools in digital history.

The consequences of digital reconstruction for research practices need to be considered when developing research environments. The discovery and aggregation of sources is the first step in the research cycle. In a digital environment, it is characterized by the change of sources used. More and more digitized material is becoming the source of research. Hitchcock [35] points out that digitized material is used as primary source for further work, but often not quoted in publications. This makes the research process increasingly less transparent as workflows or research methods cannot be criticized based on these uncited sources. Hitchcock further elaborates that corpora are constructed online using search engines, so it is not evident how the documents are compiled, blurring the methodology used with the conclusions reached [35]. Even if search strategies are documents, it is not possible to reproduce the results because of the continuous changes in the underlying data. Classical search tools at least track different versions, so that researchers can trace the results of other scholars. To adhere to scientific standards, simply referencing the search engine or website and the specific time of use is not enough, although this is often recommended in the standard rules for quoting websites. We need better web archives and workflows for referencing the objects within them in a sustainable way.

One way of adapting research practices to the conditions of using digital resources is by integrating them into research environments, for example by offering stable and citable references for each product of the research process. History as a discipline has to think about further ways of handling digital sources, especially if these are historical reconstructions. The reconstruction of material, whether as a source or a result, needs to be transparent and traceable.

In particular, if the reconstruction is the result of the research, appropriate publication practices need to be supported by the virtual research environment. The source data must be separable from the interpretation. Standards for the historical critique of sources (in German “Quellenkritik”) in digital environments have to be developed. It should be possible to re-use the resulting publication by embedding it into a larger or different context. For this, the structure of publications needs to be preserved in an editable format, which means that fixed formats like PDF are no longer suitable. Emerging technologies and practices such as Linked Data can help to connect different perspectives and contexts and to make relations more visible.

Ideally, every reconstruction should be handled as a research process whose result is the given reconstructed research object. Only if the reconstruction itself adheres to scientific standards such as validity, reliability and utility, it can be evaluated and assessed by scholars using it as a source for further studies. There is still a lack of

standards and tools for granular reference to multidimensional objects online. Links to and from supporting sources are required in order to comply with scholarly standards. Only the embedding of several contexts makes the digital reconstruction valuable and adds information. To achieve this, standards must not only target reconstruction but also reflect upon it from different perspectives such as preservation and publication. One step in this direction would be a TEI for objects as described above. Driven by examples, an Object Encoding Initiative (OEI) should propose a standard format to determine how data and metadata can be attached to an object, how this data should be stored and preserved on a long-term basis. These measures would make reconstructions more transparent and comparable, bringing us one step closer to meaningful data publication in the humanities.

Acknowledgements: We would like to thank Klaus Thoden from the Max Planck Institute for the History of Science for giving feedback on this article.

URLs quoted: The nature of this article made it necessary to quote a number of websites. We last checked all the links while finishing this article in July 2016. We chose URLs that we believe are stable enough to serve as examples for this article for a reasonable amount of time. We are in doubt about the sustainability of these references but think this only reiterates the importance of establishing a sustainable infrastructure for the (Digital) Humanities.

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